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The role of stress and word size in Spanish speech segmentation

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Abstract: In English, the predominance of stressed syllables as word onsets aids lexical segmentation in degraded listening conditions. Yet it is unlikely that these findings would readily transfer to languages with differing rhythmic structure. In the current study, the authors seek to examine whether listeners exploit both common word size (syllable number) and stress cues to aid lexical segmentation in Spanish. Forty-seven Spanish-speaking listeners transcribed two-word Spanish phrases in noise. As predicted by the statistical probabilities of Spanish, error analysis revealed that listeners preferred two- and three-syllable words with penultimate stress in their attempts to parse the degraded speech signal. These findings provide insight into the importance of stress in tandem with word size in the segmentation of Spanish words and suggest testable hypotheses for cross-linguistic studies that examine the effects of degraded acoustic cues on lexical segmentation.

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1. Introduction

The fundamental task in deciphering connected speech is to determine where one word ends and the next word begins. Lexical boundary errors (LBEs) are the result of incorrectly segmenting the acoustic stream into its constituent words. For example, a listener might mishear the phrase, "time her sprinting" as "timer sprinting," thereby mistakenly deleting the boundary between "time" and "her." Alternatively, a listener might mishear the phrase as "time for spring tea," thereby mistakenly inserting a lexical boundary between the syllables in "sprinting." Cutler and her colleague leveraged such LBEs to test their hypothesis that listeners exploit the statistics of English syllable stress to guide lexical segmentation (Cutler and Butterfield, 1992). Namely, erroneous insertions of lexical boundaries tend to occur most frequently immediately preceding stressed syllables, which coincide with the high frequency of words with initial-syllable stress or stressed single syllable words. Therefore, the success of LBE analysis as a tool for understanding English language-specific strategies for segmentation hinges on a strong theoretical framework that offers clear and testable predictions specifically for the English language (see Cutler and Butterfield, 1992; Mattys *et al.*, 2005). Such work has furthered our understanding of the cues listeners rely upon in deciphering not only speech in noise, but also speech that is clinically disordered (Liss *et al.*, 1998, 2000; McAuliffe *et al.*, 2013; Spitzer *et al.*, 2009). Thus, LBE analyses—in tandem with acoustic analysis of the degraded speech signal—has allowed for modeling and

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prediction of listener performance based on the presence and quality of important acoustic cues in the speech signal.

To date, there has been minimal transfer of this LBE analysis paradigm to languages that differ considerably from English in terms of rhythmic structure and segmentation cues. Progress toward this goal may prove important for understanding the perceptual challenges posed by degraded or disordered speech cross-linguistically. Here, we focus on Spanish speech because, unlike English, it is a low syllabic contrastivity language, wherein syllable durations tend in the direction of isochrony (White and Mattys, 2007). Thus, in a degraded sound environment, syllable stress contrasts alone are likely not sufficient cues to identify word onsets.

Accordingly, syllable stress as a cue to lexical segmentation has been investigated in Spanish without a clear outcome. It has been shown that Spanish speakers exploit stressed syllables as a segmentation cue for disyllabic penultimate words, much like that seen in English (Sebastián-Gallés and Costa, 1997). For example, Sebastián-Gallés and Costa (1997) show that Spanish speakers were faster to spot CVC words embedded in nonce words that exhibited penultimate stress than in nonce words that exhibited ultima stress. Similarly, Soto-Faraco and Sebastián-Gallés (2001) show that in a cross-modal priming experiment, subjects were successfully primed by the presence of initial-syllable stress in disyllabic items. Yet, when stress occurs word-medially, Toro-Soto and colleagues (2007) demonstrated that Spanish speakers do not rely upon syllable stress to segment trisyllabic penultimate items embedded in a speech stream. This led to the hypothesis that in order to be of use as a segmentation cue, syllable stress must occur in a word-edge (Tyler and Cutler, 2009). Thus, unlike English, syllable stress alone is insufficient to drive lexical segmentation decisions in Spanish, as the stress cue seems to be conditioned on syllable location within multisyllabic words.

Given this pattern of lexical segmentation findings in Spanish, we hypothesize here that listeners exploit the statistics of the most common word size (i.e., syllable number) *and* the associated primary stress location within these words. Whereas the most frequently occurring word size in English is single syllable (Cutler and Butterfield, 1992), the most common word size in Spanish is disyllabic, followed by trisyllabic items. Together disyllabic and trisyllabic words comprise 90% of tokens in Spanish (Vitevitch and Rodriguez, 2004; Pons and Bosch, 2010). In terms of stress patterns, penultimate syllable stress accounts for an estimated 64%–80% of all Spanish words (Pons and Bosch, 2010; Toro-Soto *et al.*, 2007). This means that the most commonly encountered word forms and stress patterns for Spanish are disyllabic penultimate words (stressed–unstressed) and trisyllabic penultimate forms (unstressed–stressed–unstressed). If lexical segmentation strategies in Spanish exploit these particular statistics, LBE analyses should reveal a preference for creating segmentations that result in two- and three-syllable words bearing penultimate stress.

The current study constitutes a preliminary analysis of LBE patterns elicited from Spanish-speaking listeners while transcribing Spanish speech in noise. The speech sample is designed to elicit LBEs in Spanish, with the goal of informing the development of phrase sets that ultimately permit interpretable LBE analysis for Spanish speakers. Here we report LBE error patterns generated by Spanish-speaking listeners in their transcriptions of Spanish speech in noise, and address two hypotheses regarding cues to lexical segmentation: (1) syllable stress is indeed used as a cue for segmentation, and (2) but that consideration of syllable stress in tandem with word size provides a more robust set of cues for segmentation.

2. Method

2.1 Stimuli

We created 30 two-word Spanish phrases with low inter-word predictability. For example, in the item pair *limones felices* (happy lemons) the two words form a grammatical phrase, but are very unlikely to co-occur in normal speech. Stimulus pairs varied in terms of word size (syllable number per word) and stress assignment per word.

In previous work testing lexical segmentation strategies in English, we have used sets of phrases that are balanced with regard to word onset stress (i.e., 50% of phrases begin with a strong[1] syllable, and the remainder begin with a weak syllable) (e.g., Liss *et al.*, 1998; Spitzer *et al.*, 2009), unlike the actual statistical probabilities of English (approximately 80 strong–20 weak). That is, these sets of phrases offer equal numbers of opportunities to mistakenly assign word onsets to either stressed or unstressed syllables (see Cutler and Butterfield, 1992). This design facilitates interpretation of the LBE results. Should listeners disproportionately insert word boundaries more often before stressed than before unstressed syllables, it is confidently interpreted to reflect a listener strategy that preferences stressed syllables as word onsets in segmentation. This paradigm has yielded robust and replicable results (Liss *et al.*, 1998, 2000; Spitzer *et al.*, 2009; McAuliffe *et al.*, 2013, 2014).

The Spanish set of phrases for the present experiment was constructed with the same motivation. Recall that the statistics of Spanish words show a preponderance of two- and three-syllable words with penultimate stress (roughly 90%). Therefore, to facilitate interpretability of the Spanish LBE analysis, we limited two- and three-syllable penultimate stress to 44% of the word pairs. For example, the item pair *flores cabeza* (flower head) contains a two-syllable word and a three-syllable word, both of which have penultimate stress. The remaining 56% of stimulus pairs varied in word size (syllable number) and stress assignment and included one- to four-syllable items with stress assignments that were antepenultimate, penultimate, or ultima. For example, *mar celador* (sea watchman) contains a single syllable word followed by a three-syllable word with ultima stress.

As a result of the stimulus phrase construction method, the opportunities for LBEs to create common word forms (two- or three-syllable penultimate stress) were *fewer* than those to create less common word forms (all others). Specifically, the complete set of two-word phrases (which can be found in the supplemental material[2]) offers 128 locations for possible lexical segmentation, corresponding with the number of syllable boundaries. Of the 128 possible segmentation locations, 40% would result in the statistically common two- or three-syllable penultimate stress sequences, and 60% would result in some other less common form. By weighting the stimulus set in the direction of statistically less common word forms, findings of a perceptual bias toward lexical segmentations that yield the more common word forms are particularly compelling.

A 49-yr-old female native speaker of Mexican Spanish read all 30 stimuli, with recording completed in a sound attenuated booth. The stimulus pairs were embedded in noise shaped to match the average spectra of sentences produced by the talker. Stimuli were presented at -3 dB signal-to-noise ratio (SNR) following a pilot experiment that demonstrated this SNR achieved approximately 50% words correct on transcription. This level of degradation ensured adequate numbers of lexical segmentation errors to support a meaningful LBE analysis.

2.2 Listener participants

A convenience sample of 47 adult Spanish-speaking listeners participated in this study. Twenty-five Spanish-speaking monolinguals were recruited in Mexico City (eight men, mean age 33 yrs; 17 women, mean age 27 yrs) and 22 Spanish-English bilinguals were recruited in the Phoenix metropolitan area (six men, mean age 32 yrs; 16 women, mean age 28 yrs). Although previous work has demonstrated that bilingual speakers' *L*2 perceptual strategies can be influenced by their *L*1 (Cutler, 2012) and vice versa (Dijkstra and Van Heuven, 2002; Marian and Spivey, 2003a,b; Spivey and Marian, 1999; Shook and Marian, 2012), comparison of the LBE patterns of the two groups revealed no differences, and therefore the data were pooled for all analyses.[3] Language status was based on self-report and all participants further reported normal hearing and vision. All participants reported Spanish to be their dominant language and that age of acquisition was before 5 years of age. Each participant received $10/165 pesos compensation in exchange for participation.

2.3 Procedure

Listeners completed the task seated in a quiet room wearing Sennheiser (Wedemark, Germany) HD280 Pro circumaural headphones. The signal volume was set to a comfortable listening level and remained unchanged across listeners. Listeners were told that they would hear Spanish phrases composed of two unrelated, but real, Spanish words. They were also told that the phrases did not make sense, they would be presented in noise, and that they were difficult to understand. Listeners were asked to type on a computer keyboard what they thought they heard, and to make their best guess if they were uncertain. Each phrase was presented once only, and all phrases were randomized across listeners. Listeners received no feedback about their performance during the course of the task.

2.4 Error coding

Prior to error coding, listeners' transcriptions were edited to correct spelling and diacritics errors. Two trained judges, both native speakers of Spanish, coded both LBEs and number of words correct. Judges were naive to the guiding hypotheses of the experiment. In order to assess LBEs, judges were explicitly instructed to compare subject responses to the target phrases to identify the presence of lexical segmentation errors and to code for the LBE type (insertion or deletion of a lexical boundary) and location (whether it occurred before a weak or strong syllable in the target). Strong syllables were regarded as those with primary stress, and weak syllables as those with secondary or no stress. This resulted in four error types: insertion before a weak syllable (IW), insertion before a strong syllable (IS), deletion before a weak syllable (DW), and deletion before a strong syllable (DS) (see Table 1 for examples of the coding protocol). This coding allows us to test the prediction that syllabic stress does indeed serve as a cue for lexical segmentation.

Up to this point, all transcript coding corresponds with that of the English LBE analysis. The departure comes in the third step, involving coding of the word size (i.e., number of syllables comprising the transcribed word) and stress assignment of the transcribed word (i.e., penultimate, antepenultimate, or ultima). For example, the response *cometa seca* (seen in Table 1) was coded as a three-syllable penultimate stress word and a two-syllable penultimate stress word, while the response *camara avion* was coded as a three-syllable antepenultimate word and a two-syllable ultima word. Some of the response items were not real words,[4] (i.e., *artefactor* or *espinoto* in Table 1) and the probable stress assignment was identified based on the unanimous, independent judgments of the two native Spanish speakers, who were unaware of the project's hypotheses.

To evaluate the hypothesis that lexical segmentation errors would favor two- and three-syllable penultimate words, we further coded each transcribed word as *predicted* (statistically favored) or *unpredicted* (statistically less favored). A predicted error type was defined as one in which the erroneous transcription resulted in two- or three-syllable words with a penultimate stress assignment, in keeping with the statistical probabilities of Spanish. An unpredicted error type was defined as words containing only one syllable or more than three syllables, and exhibiting any stress assignment (i.e., antepenultimate, penultimate, or ultima stress). For example, the response *cometa seca* includes two predicted errors—one three-syllable and one two-syllable word with penultimate stress, respectively. However, the item *extrañamos casa* contains an unpredicted error in the four-syllable penultimate word *extrañamos.* It should be noted that we use the term *unpredicted* to refer to less statistically common types of words and stress assignment, and not to suggest they are anomalous.

2.5 Statistical analysis

The LBE paradigm generates a large corpus from which to evaluate error distributions based on coding. Because it is a corpus of all errors committed by all listeners during the transcription of the speech in noise, there is no variance in the LBE data set. Thus, in line with previous studies, we tested the first hypothesis regarding syllable stress as a lexical segmentation cue with a nonparametric chi-square analysis. This determined whether the observed LBE distributions extracted from listener transcripts were sampled from the expected distribution derived from the expected LBE distributions (e.g., see Liss *et al.*, 1998, 2000; McAuliffe *et al.*, 2013). The second hypothesis, regarding syllable stress and words size (more common versus less common), was evaluated using a paired-sample t-test and descriptive statistics ($p < 0.05$).

3. Results and discussion

3.1 LBE analysis

To assess listeners' use of syllable stress as a cue for lexical segmentation, we examined the obtained LBE distributions across IS, IW, DS, and DW. If syllable stress is a cue, the LBE distribution should show a bias toward certain error types and against others.

Table 1. Examples of Spanish language LBE coding; cells containing predicted errors (two- or three-syllable words with penultimate stress) are marked with an asterisk.

Stimuli	Error Response	IS	IW	DS	DW
come ta**si**ta	co**me**ta **se**ca*	1			1
ex**tra**ña mos**ta**za	extra**ña**mos **ca**sa*	1			1
arte fac**to**res	arte**fac**tor es		1		1
co**rro**zas pi**lo**to	**car**ros espi**no**to*		1		1
arte**fa**cto **plan**	**ar**te facto**plan**	1		1	
ma**ri**no **me**sa	la mini**mi**za	1		1	
cama**ra**da **bien**	**ca**mara av**ion***		1	1	
ma**no**jo **li**bro	**ma**no pe**li**gro*		1	1	

If the LBE error distribution coincides with the number of opportunities to commit each of the error types, we can conclude that syllable stress is not a salient cue. To evaluate this, we conducted a chi-square goodness of fit test, using the distribution of opportunities for LBEs as the expected values and the actual distributions as the observed values. The results were highly significant, indicating that the observed results obtained from listener transcripts were not sampled from the same distribution as the expected results based on the opportunities to commit these error types [$X^2(3) = 22.845$, $p < 0.0001$]. This is indicative of the influence of syllable number and syllable stress location on listener strategies for lexical segmentation decisions.

Inspection of the distributions reveals two primary sources for these differences as seen in Fig. 1. First, the left chart (i.e., "expected LBE outcomes") indicates that the vast majority of error type opportunities were lexical boundary insertions (76%) rather than deletions (24%). The insertion–deletion distribution for the actual LBEs obtained from listener transcripts (right chart, "observed LBE outcomes") indicated a much lower number of lexical boundary insertions than expected (55%), and a much higher number of deletions than expected (45%). This pattern is consistent with a perceptual preference to delete lexical boundaries relative to the opportunities to do so, which would be consistent with the preponderance of multisyllabic word forms as dictated by Spanish statistics. Said another way, lexical boundary deletion results in multisyllabic words.

A second source of differences between the two distributions in Fig. 1 is in the location of errors (before weak or strong syllables) within the LBE insertions category (i.e., IS and IW errors). While the actual deletion errors (DS and DW) conformed to the distribution of the opportunities to commit these errors, the same was not true for LBE insertions. If we restrict our analyses to the insertion errors only, then it is apparent the target phrases contain many more opportunities to commit LBE insertions before weak syllables (64% of all insertions) than before strong (36% of all insertions), as shown in the left chart. The right chart shows that the actual insertion errors occurred roughly equally before weak and strong syllables (49% vs 51% of all insertion errors, respectively). This suggests a perceptual preference for treating strong syllables as word onsets when erroneously inserting a lexical boundary. Such a finding makes sense for languages that are comprised predominantly of strong word onsets, like English. However, it does not square well with Spanish lexical statistics, except in the cases of single syllable strong words and disyllabic penultimate stress words (Sebastián-Gallés and Costa, 1997). As expected, a simple LBE analysis that is sufficient for explaining English segmentation strategy cue use is insufficient for Spanish. Syllable stress cues clearly are in play for this corpus of errors because of the unexpectedly high rate of lexical boundary deletions, and the unexpectedly high proportion of insertion errors that occur before stressed syllables in comparison to before weak syllables. That is, if stress cues were not in play, the actual error distribution would align with the opportunities to commit the various lexical segmentation error types and locations as illustrated by the expected LBE outcomes in the left graph in Fig. 1.

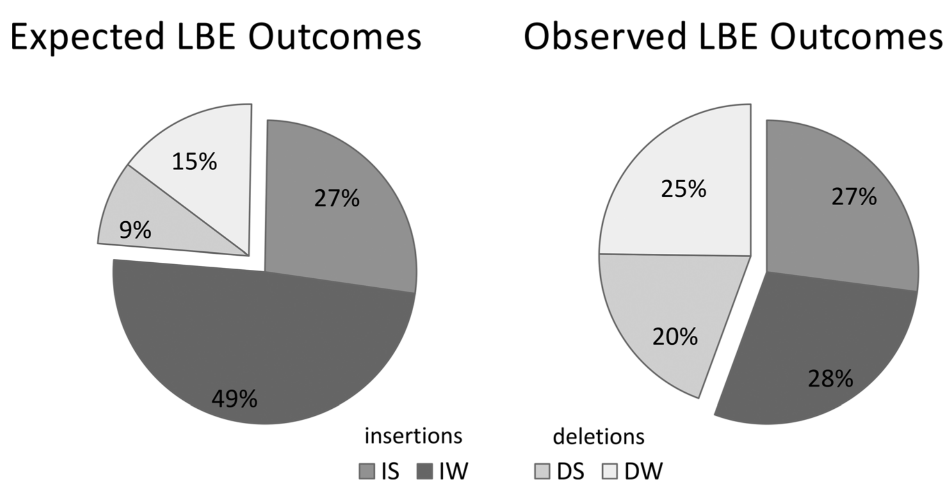

Fig. 1. Expected and observed LBE outcomes; the graph on the left illustrates the distribution of expected LBEs, while the graph on the right illustrates the distribution of the actual errors observed in participants' responses. The exploded slices represent the set of insertion errors (dark colors) versus the deletion errors (light colors).

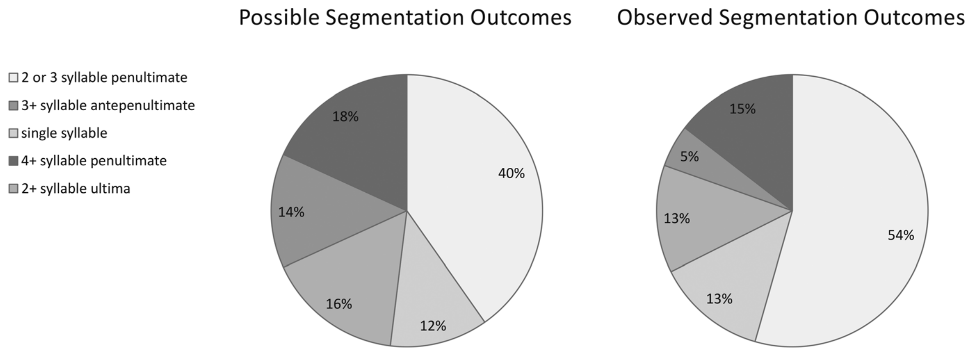

Fig. 2. Expected and observed segmentation outcomes; the graph on the left illustrates the distribution of the expected segmentation outcomes, while the graph on the right illustrates the distribution of the actual segmentation outcomes in participants' responses. The two or three syllable penultimate percentages represent the predicted outcomes, while all other categories are unpredicted.

3.2 Word size and stress assignment in LBEs

Our primary hypothesis was that participants would be influenced by the statistics of the language and be biased to commit segmentation errors that yielded two- and three-syllable words with penultimate stress significantly more often than unpredicted error types other stress and syllable numbers. There were 128 locations (between syllables) to make lexical segmentations within the stimulus phrase set. Of these, segmenting at 40% of these locations would result in two- or three- syllable words with penultimate stress; and segmenting at the remaining 60% of these locations would result in all other word size and stress assignments. This is shown in the left chart of Fig. 2 ("possible segmentation outcomes"). However, the actual proportions obtained from the listener transcripts for predicted versus unpredicted error distribution were 54%–46%, respectively, as shown in the right chart. A paired-sample *t*-test showed a significant difference between the proportion of participants' predicted and unpredicted errors ($t(46) = 8.371$, $p < 0.001$). Hence, this supports the hypothesis that Spanish speakers exhibited a preference for the predicted two- and three-syllables words with penultimate stress.

4. Conclusion

This study aimed to elicit and analyze lexical segmentation errors from degraded Spanish speech, with the goal of informing the development of balanced phrase sets that ultimately permit interpretable LBE analysis for Spanish speakers. The current findings support prior reports that the cue of primary syllable stress is insufficient in Spanish to drive lexical segmentation decisions. Instead, the strong preference for two- and three-syllable responses with penultimate stress found in the LBEs support a novel hypothesis listeners appear to jointly exploit word size and stress location as lexical segmentation cues. This coincides with the statistics of spoken Spanish as would be expected from the statistical drivers of lexical segmentation in English and other languages. Identifying the role of both stress and word size as a segmentation cue for speakers provides important cross-linguistic insights into the study of speech perception in adverse listening situations. Finally, this information is critical to the development of balanced stimulus sets for the study of intelligibility deficits in Spanish speakers with speech disorders such as dysarthria, as well as for Spanish speakers with cochlear implants.

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References and links

[1]English is regarded as a high contrastivity language because of the juxtaposition of strong and weak syllables, wherein strong syllables tend to hold primary stress, longer duration, full vowels, and distinctive pitch and loudness as compared with weak syllables (Cutler and Butterfield, 1992; Liss *et al.*, 2000; Mattys *et al.*, 2005). Thus, in English, strong syllables are always stressed syllables (Cutler and Butterfield, 1992), and we use these terms interchangeably.

[2]See supplemental material at http://dx.doi.org/10.1121/1.4971227 for a complete list of the 2-word phrases used as stimuli.

[3]Coded LBEs were tallied separately for mono- and bilingual participants to create two corpora of errors. The total number of LBEs in the corpora was similar, with slightly more in the bilingual than in the monolingual transcripts (360 vs 320, respectively). Also, the distributions of LBEs across type and location within each corpus were roughly equally proportioned across the four error types (IS, IW, DS, and DW), resulting in nonsignificant chi-square tests of independence [monolingual $X^2 = 0.075$, $p = 0.783$; bilingual $X^2 = 0.221$, $p = 0.638$]. Further, a chi-square goodness of fit test, using monolingual LBE percentages as expected and bilingual LBE percentages as observed, also was nonsignificant [$X^2(3) = 1.68$, $p = 0.64$]. Additionally, the paired sample *t*-test evaluating significant differences between the number of single syllable responses from monolinguals and bilinguals was also nonsignificant ($t(58) = 0.611$, $p > 0.05$). As no influence of *L*2 on *L*1 segmentation could be identified in these data, the two corpora were collapsed into a single set of coded Spanish transcripts for more robust subsequent analyses.

[4]Responses consisted of a total of 813 words. Of these, 40 were nonwords (approximately 6% of all responses). Nonwords were included in the analysis.

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